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ABSTRACT

Noting that current cognitive theories focus on the belief that knowledge is an organized collection of long-term structures upon which various processing mechanisms operate, this paper argues that mental functioning may be more readily characterized if the idea of abstract long-term associations and structures is abandoned. It proposes a model of cognition in which mental relations are transient functional relations, and in which psychological permanence is a functional characteristic of the neuronal system. It explains cognition and other aspects of mental life in terms of the activity of anatomically distributed constellations of neuronal elements, which are conceived of as physiological microsystems that are capable of generating specialized awareness experiences. The paper terms the overall mental counterpart of the combined activity of these elements "schema-of-the-moment" (SOM), a constantly changing phenomenon involving both global and focal experiences. It then discusses the three distinguishable, but not separate, components of SOM: the background, dominant, and independently functioning components. (Author/FL)

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Technical Report No. 304

MORE ON THE FUNCTIONAL VIEW OF COGNITION: A BIOFUNCTIONAL MODEL OF MENTAL CONTENT, MENTAL STRUCTURES, AWARENESS, AND ATTENTION

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Abstract

Central to current cognitive theories is the belief that knowledge is an organized collection of long-term structures upon which various information processing mechanisms operate. Consequently much research has been devoted to investigating the organizational and processing aspects of knowledge representations. This paper proposes a shift in the locus of theoretical analysis. Following Bartlett, we argue that mental functioning may be more readily characterized if the idea of abstract long-term associations and structures is abandoned. An account of cognition is proposed in which mental relations are transient functional relations, and in which psychological permanence is a functional characteristic of the neuronal system. Cognition and other aspects of mental life are explained in terms of the activity of anatomically distributed constellations of neuronal elements. These elements are conceived of as physiological microsystems which are capable of generating specialized awareness experiences. The overall mental counterpart of the combined activity of these elements we call the schema-of-the-moment. We hope that the model we are proposing can contribute to bridging the gap between cognitive psychology and the neurosciences.

More on the Functional View of Cognition: A Biofunctional Model of Mental Content, Mental Structures, Awareness, and Attention

This paper is the result of a substantial revision of Iran-Nejad and Ortony (1982). The revision was originally motivated by the desire to clarify some of the areas in which the earlier paper was vague. The result, however, turned out to be so different from the original that this separate report seemed warranted.

When psychological theories employ theoretical terms like memory, representation, and structure, they often do so because the descriptions and explanations of psychologically interesting phenomena that result are at a sufficiently abstract level to be informative and intelligible. As a first step in theory construction the use of theoretical terms at a level of description close to the phenomenological level is helpful, and probably indispensable. However, the theories that result are often rather vague and ill-constrained, and tend to lack predictive power (see, for example, reviews of schema theory by Alba & Hasher, 1983 and Thorndyke & Yekovitch, 1980). If this is true, then a sensible next step would be to try to account for the phenomena of interest in terms of more concrete constructs. In this paper we offer some proposals for taking this step. To do this, we maintain that it is necessary to reconsider the traditional notion of knowledge

representations as long-term (essentially) static structures. We shall argue that the nature of mental content, schemata, awareness, and attention may be more readily specifiable in terms of concrete neurophysiologically-realistic constructs if one abandons the notion of long-term static knowledge representations in favor of transient dynamic patterns.

An interesting aspect of attempting to employ more concrete theoretical constructs in psychological explanations is that it sharpens the distinction between artificial intelligence and cognitive psychology. The two cease to be simply methodological variants of one another. Artificial intelligence is concerned with characterizing cognition and intelligence _in abstracto_; its goal is a "system-independent" specification of the cognitive software. Theories in cognitive psychology must be more constrained. They need to take into account not only the constraints imposed by people's behavior, but also the sort of constraints likely to be imposed by the biological hardware, since it is presumably these that give cognition its uniquely human quality. Thus, while it might seem reasonable to start by assuming that cognition can be explained solely in terms of the formal characteristics of psychological software, it may well be that this assumption cannot be upheld. Certainly, arguments have been presented to this effect. For instance, Eliashberg (1981) examined the properties of hypothetical machines and argued that "the popular thesis that the problem of the algorithms performed by the brain . . . has but little to do with the problem of brain hardware" is inadequate.

Similarly, Kugler, Kelso, and Turvey (1980) claimed that "abstract automata formally equivalent to the turing machine do not satisfy the natural constraints that must be met by any actual, evolved epistemic agent. . . . The cost variables imposed on organisms by the laws of physics and biology are quite different from those formally placed on the workings of abstract automata" (p. 5). We share these views, believing that more attention needs to be devoted to the functional characteristics of the physical systems that exhibit the phenomena of interest. In fact, we believe that the ultimate goal of cognitive psychology ought to be the specification of the way in which the functional properties of the nervous system make cognition possible.

There are other reasons for attempting to base an account of cognition on relatively concrete constructs. One is that neuroscientific models in general tend to be parsimonious. A striking example is provided by the recent advances (e.g. Berlin & Kay, 1969; Kay & McDaniel, 1978) in understanding the relationship between the perception of color and the meaning of color terms in different languages. It now seems that "all the basic color categories of the languages of the world are based on . . . six fundamental neural response categories, whose structures are determined by the firing patterns of . . . cells in the visual pathway" (Kay, 1981, p. 64). Only after taking account of the physiology of color perception did it become possible to give a

unified explanation of the principles governing the way in which people in different cultures speaking different languages talk about the world of color.

For us, the most compelling reason for using relatively concrete constructs in psychological theories is that their use avoids some of the problems related to the metaphorical nature of the theoretical terms traditionally employed. Terms like memory and knowledge-representation are complex abstractions, and it is not at all clear to what they refer. Many psychologists (e.g. Bartlett, 1932; Bransford, McCarrell, Franks & Nitsch, 1977; Jenkins, 1977; Pylyshyn, 1973) have objected to the heavy theoretical burden imposed upon such terms. The problem is that often the essentially metaphorical use of these concepts can give rise to misleading implications. For example, we ordinarily talk about mental representations being stored in memory, searched for, and retrieved. It is easy to see how, if taken literally, such ideas can lead to the conclusion that people's heads are populated with a huge number of pre-packaged permanent structures corresponding to everything they know. We will refer to the view that postulates permanent knowledge structures as the "structural" approach and to the alternative view, that treats mental phenomena as resulting from transient patterns directly created by the functioning of the biological hardware, as the "biofunctional" approach.

Not only does the biofunctional approach differ from the structural approach in its rejection of long-term mental structures, but it also differs in the way it views the dynamic aspect of

cognition. The structural view deals with the dynamic aspects of the mind in terms of searches for and changes to permanently-stored knowledge structures. Since we question the need to postulate such structures, we try to avoid this way of dealing with the problem: If there are no permanent cognitive structures, then they cannot be found or changed. In biofunctional terms, cognitive patterns are viewed as transient dynamic structures. In short, along with Bartlett, Bransford and his colleagues (e.g., Bransford, Nitsch & Franks, 1977), and Dennett (1983), we argue that cognition does not involve the selection of pre-existing cognitive structures, rather it involves the creation and re-creation of transient ones. We wish to emphasize, however, that our arguments against the use of structural concepts must not be interpreted as an attempt to free all psychological exposition from structural terms. As Freeman (1975) points out, even at the more concrete levels of exposition "it is reasonable and perhaps necessary to describe the manipulations of the central state with concepts that are both generalized and familiar from common experience . . . [although] . . . there is not and cannot be an a priori relation between those concepts and the dynamics of the central neural mechanisms" (p. 414). Our view is that as long as the prevailing theoretical context clarifies the meaning of "structural" terms, their use should cause no problems. When, on the other hand, the terminology itself determines the underlying theoretical context, as is sometimes the case when long-term memory metaphors are used, we believe an inappropriate picture of the nature of mental functioning arises.

Over the years cognitive psychologists have gathered a great deal of empirical data that seem to support various aspects of the structural approach. However, there is also a great deal of indirect evidence in the neuroscientific literature that contradicts it (see, e.g., Freeman, 1975; Uttal, 1978). While there is currently no direct psychological evidence supporting a biofunctional approach (for a discussion of some indirect evidence, see Schallert, 1982; Shanklin, 1981), the major assumption that differentiates the structural and the biofunctional perspectives (i.e., mental structures are transient biofunctional patterns) is shared by many current psychobiologists and neuroscientists (see Edelman, 1978; Freeman, 1975; John, 1967, 1972; Katchalsky, Rowland & Blumenthal, 1974; Uttal, 1978).

Our account of cognition attempts to bridge the conceptual gap that results from the absence of a common language between cognitive psychology and neurophysiology. Although one might think that compatibility of psychological theories with what is known about the human nervous system is an obvious minimal requirement, such compatibility is frequently conspicuously absent. For example, Schmitt (1978) noted that "many theories of higher brain function (learning, memory, perception, self-awareness, consciousness) have been proposed; but in general they lack cogency with respect to established anatomical and physiological facts and are without biophysical and biochemical plausibility" (p. 1). Similarly, Gallistel (1980) in discussing a psychological model of the control of limb movement (Adams, 1977) claims that modern neurophysiological

work on the mechanisms of co-ordination renders the theory untenable. The message is clear: psychologists need to attend more closely to neuroscientific research.

The problem as it relates to psychological research, therefore, does not seem to be the absence of biologically plausible theories. Such theories exist in the work of authors like Donchin (1981), Freeman (e.g., 1975), Grossberg (e.g., 1982), John (e.g., John, 1972; John & Schwartz, 1978), Maturana (1978), O'Keefe and Nadel (1978, 1979), and Uttal (1978). Rather, in some subtle way, the problem seems to relate to the deep-seatedness of the influence of the structural paradigm on cognitive psychology. The structural bias, we believe, has drawn attention away from existing neuroscientific theories many of which are in essence biofunctional. For instance, Jenkins (1981) noted that structural psychology frequently cites William James' treatment of habit formation and ignores his "true functionalism."

The view we are proposing is based on theoretical constructs at three interacting levels: (a) the (neuroanatomic) micro-organizational level, (b) the biofunctional macro-organizational level, and (c) the psychological level. At the micro-organizational level, we will attempt to characterize a physically unitary and functionally autonomous <u>microsystem</u> as the most elementary biofunctional unit. Consistent with the current trend in neurophysiology, we will assume that neural microsystems correspond to neurons, and will often refer to them as (neuronal) <u>elements</u>. At the macro-organizational level, we will attempt to characterize what

we refer to as macroactive structures. These are patterns of activity resulting from sirultaneous functioning of physically distributed elements. Following Freeman (1975), we will refer to the totality of active elements in the nervous system as the mass action system. Finally, at the mental level, we will attempt to characterize the central concept in the biofunctional model, namely what we call the schema-of-the-moment. This is a transient mental structure that arises from activity in the mass action system. We use the term schema-of-the-moment for two main reasons. First, we argue that it is in terms of this "functioning mass of the moment," as Bartlett (1932) and Head (1920) called it, that all cognitive phenomena (comprehension, learning, remembering, awareness, attention, etc.) take place. Second, the schema-of-the-moment is assumed to be the only mental pattern in existence in a given individual at a particular time--everything else is neuroanatomic or neurophysiological.

The discussions in this paper are organized in three main sections around the notion of the schema-of-the-moment. The first discusses a number of important background questions including that of how it might be possible for widely distributed elements to intercommunicate. The second section discusses the pre-subjective foundations of the schema-of-the-moment. Exactly what neuronal microsystems are, how they function, how they generate psychological qualities, how they are distributed, and how they functionally relate to one another. In the third section we describe the main characteristics and functions of the schema-of-the-moment.

The Schema-of-the-Moment: Some Preliminary Issues

The Foundations of the Structural View

There are two fundamental assumptions upon which the structural view of cognition is based. One is that mental life can be characterized in terms of various kinds of cognitive processes. The other is that these processes are performed on long-term knowledge representations. Neither of these assumptions are part of the biofunctional view.

Most structural theories (e.g., schema theories) assume that the dynamic aspects of cognition can be accommodated in information processing terms. For example, the schema selection process is assumed to be the result of some kind of search or retrieval mechanism. The central concept employed in information processing models to capture the dynamic (i.e., the processing) aspect is that of an input-transformation-output sequence--the system accepts inputs either from memory or from outside, performs transformations on them, and produces resultant outputs, that get stored in memory or are manifested in verbal or nonverbal behavior.[1] The inputs and outputs themselves are essentially static. Typically, they are knowledge representations--data structures that exist independently of the dynamic component. In general, information processing models are concerned with "what happens to information about a stimulus from the 'real world' as it passes through the system" (Klatzky, 1975, p. 11).

We believe that many of the questions addressed by information processing theories arise only as a result of the assumption that

the "objects" of processing possess some independent existential status. In the biofunctional model, the system is dynamic but it does not process anything; there is no object of processing. Knowledge is considered to be a transient phenomenon created and re-created by the functioning of the biological hardware. What is created lasts only while the underlying biological system that creates it continues to be active. Nothing nonbiological is stored, and apart from its potential to be re-recreated, knowledge has no permanent existence.

An analogy based on the functioning of the endocrine glandular system may serve to clarify the contrast between the re-creation and input-transformation-output views. There is a group of cells located in the cortical part of the adrenal glands. These cells, when activated, produce the hormone, cortisol. The cells themselves get activated by another hormone, ACTH (adrenocorticotropic hormone), released in the anterior part of the pituitary gland. The crucial point is that there is absolutely no input-transformation-output relationship between the stimulator ACTH and the produced cortisol. Adrenal cortical cells, once activated, create the cortisol through, for example, biochemical operations based on substances other than those contained in ACTH. It is this dissociation between the input and the output--mediated by the intrinsic functional properties of the specialized organismic system--that renders any system-independent ACTH-to-cortisol transformation rules, or any precise formal description of the product based on them, inappropriate. The qualitative properties of

the output are determined entirely by the biofunctional properties of the specialized cells in the adrenal glands, even though there may sometimes be a (linear or nonlinear) quantitative relation between the input and the output. This qualitative dissociation between the input and the output means that, in principle, cortisol can be produced in the total absence of ACTH, and that cortisol might fail to be produced in the presence of ACTH. In much the same way, neuronal mechanisms active at a given time combine functionally to create a transient cognitive structure. Such a dynamic functional organization is input-independent in the sense that there exists a qualitative dissociation between the characteristics inherent in the external stimulation and the functional properties of the neuronal system. Conceptualizing the dynamic aspect of cognition in this way eliminates the need to postulate the preservation of long-term knowledge structures.

Ironically, Bartlett (1932), who is often cited in the context of structural views of cognition (especially with respect to schema theory), was strongly opposed to the idea of long-term mental representations and favored some kind of functional account. He made this point explicitly when he stated that his approach was based on the "study of the conditions of organic and mental functions, rather than ... [on] an analysis of mental structures" and that "it was ... the latter standpoint which developed the traditional principles of association" (p. 304). Our distinction between structure and function is similar to that made by Bartlett. He believed that a functional approach was necessary to explain a

number of observations that puzzled him. For example, he found it curious that although incoming information is learned only if it is incorporated into what he called the "organized mass of the moment," later recollections of such information, in recall or in thinking, do not always occur "en masse." What happens to the strong tie established between the input information and the schema in terms of which it was learned? According to Bartlett, "In remembering, we appear to be dominated by particular past events," as opposed to past schemata in their intact original form. He stated that what was once an "active organized setting looks as if it has somehow undergone a change, making it possible for parts of it which are remote in time to have a leading role to play" (p. 202). He was also puzzled by the fact that incoming information is learned in a chronological sequence in which every new item is strongly influenced by the one before it. However, later recall of an item does not seem to favor recitation of the entire sequence and would be highly inefficient and inappropriate if it did (see p. 219). Thus, Bartlett concluded that thinking, for instance, is only "possible when a way has been found of breaking up the 'massed' influence of past stimuli and situations, only when a device has already been discovered for conquering the sequential tyranny of past reactions" (p. 225). This, according to Bartlett, would be possible if schema relations were conceived of as transient (i.e., functional) relations.

Bartlett also favored the functional approach over the structural approach because he found unacceptable the idea that in

an associative structure each element "retains its essential individuality." He preferred to think of elements as combining into an organized mass. In an organized mass, the components are not related by association. Rather, each element loses its identity and becomes an integrated part of the combination in the same way that, when oxygen and hydrogen combine to produce water, the properties of these elements are no longer evident. Furthermore, the resultant structure comes to possess emergent properties that are not present in any of the component elements in the same way that water possesses properties not possessed by its component elements.

Thus, far from taking mental structures as given, Bartlett was concerned with two complementary problems: how elements combine into a schema, and how schema elements manage to free themselves from the shackles of past combinations (i.e., how they "re-individualize" themselves). While he apparently believed that this was possible only if schema elements, when combining, entered into functional relations, he could not decide what sort of elements would make this possible, reluctantly picking the image as his candidate. His reluctance seems to have been based in part on a realization that images are overly subjective and insufficiently biological (see p. 220). Images are themselves cognitive structures, and Bartlett apparently felt that they lacked the appropriate combinatorial properties that the true elements in a functioning system would require. Our solution, to be discussed later, is to specify, at the pre-subjective neuronal level, elements that are <u>biofunctionally</u> (and, only by extrapolation, psychologically) primitive.

Mental Relations and Brain Connections

Once the notion of long-term cognitive structures is abandoned, the question arises as to the relation between the neuroanatomic network and the cognitive organization. In particular, it becomes necessary to consider the extent to which, if any, there is structural conformity between the two systems. Minsky (1980) and Norman (1980) draw attention to the problem of specifying this relation and refer to it as the "crossbar" and "address" problem respectively. According to Minsky, "this problem confronts every brain theory that tries to explain how the mind is capable of any great range of 'associations'" (p. 124). According to Norman, "associations among memory concepts . . . [imply] much too much knowledge of the wire (or of its biological equivalent) that is to snake its way among the already existing stuff" (p. 22).

In theory, there are at least three types of solutions all of which have been proposed at one time or another. The first possibility is to postulate a particular (pre-existing or, rather, pre-functional) neuroanatomic pattern, partial or complete, corresponding to every cognitive pattern. This essentially amounts to mapping the structural cognitive network into an isomorphic neuroanatomic network. Such isomorphism was a major psychobiological premise in Gestalt psychology (see Uttal, 1978 for a discussion of this). Isomorphism is also implicit in the connectionist approach to neural modeling of semantic networks, whether these models represent concepts as particular hardware units

(Feldman, 1979, 1981; Fahlman, 1981) or as patterns of activity in localized cell assemblies (Hinton, 1981).

The second possibility is that the neuronal network is analogous to some sort of sophisticated telephone network. By allowing directional hard-wired routes between elements, the nervous system would somehow generate two-unit or multi-unit (transient) communication patterns. A telephone network is directional because the initiating unit must know the "address" of the target unit(s). Directional connectionist models imply "that 'remembering' requires the discharge of those particular cells which constitute the new line, and those of the cells to which the line is directed" (John, 1972). John and his colleagues (e.g., John, 1967, 1972; John & Schwartz, 1978; Thatcher & John, 1977) have been among the most outspoken critics of connectionist models, arguing that, for example, responses to even the most elementary stimuli (e.g., a flash of light or a click) are made by cells distributed throughout the brain and that a given cell participates in many functional patterns. Although few psychologists and neuroscientists still subscribe to the type of connectionism that John criticized, connectionism in some form or another is still widely embraced (see, for example, the essays in Hinton & Anderson, 1981). It is now generally recognized that mental relations are variable. But modern connectionists attempt to accommodate such variability in terms of synaptic plasticity. As Uttal (1978) has convincingly argued, the large conceptual gap between synaptic plasticity (defined in terms of synaptic weights, facilitation levels, etc.) and complex mental

phenomena renders synaptic connectionism implausible (pp. 540-541).

Another line of argument against connectionist models comes from recent developments in theoretical chemistry and their application to activity in masses of neurons (Freeman, 1975; Katchalsky et al. 1974). The thrust of the argument, which is incidentally highly reminiscent of Bartlett's criticism of associative connectionism cited earlier, is that neural activity, far from occurring in terms of independent hardware units joined by neuroanatomic connections, tends towards organization and self-consistency in a fashion analogous to that occurring in diffusion-coupled chemical reactions. According to Freeman (1975), these ideas "lead to expectations of neural activity quite different from the discrete characteristics of activity in networks" (p. 8). Freeman claims that given this perspective, what emerges "from the study of neural mass action is not merely an extension of current understanding; it is revolutionary in the sense defined by Kuhn (1970)" (p. 8).

Incidentally, it must be noted that anticonnectionists do not reject the existence of precise neuroanatomic connections. Rather, they maintain that although precise neural connections exist at the anatomic level, it is necessary to distinguish between anatomical connections and functional relations, and that a set or constellation of neurons having fixed anatomical connections may admit of many functional patterns (Freeman, 1975).

If synaptic plasticity or modifiability does indeed fail to adequately explain functional connections among elements, the

nervous system must accommodate variable functional relations among elements in some other way. The fact that neuronal elements are capable of interacting with other distant neuronal elements that are distributed throughout the brain suggests that there might exist within the nervous system some sort of relational medium to make such interaction-at-a-distance possible. The third possibility, therefore, and the one we find most plausible, is that in addition to synaptic modifiability, the neuronal network also communicates through an all-spreading nondirectional relational medium. Such a medium would allow (within amplitude, etc., constraints) nondirectional conductance of electrical or chemical energy (signals) in addition to directional element-to-element interactions.

In a totally nondirectional network every signal can potentially reach all specialized units and no signal is aimed at any particular unit directly. Thus, the initiating unit does not need to know the address of the target unit. Rather, target units are specialized to get activated in response to (or "to recognize") the functioning of the initiating unit that produces the signal, and to remain indifferent to the functioning (and, thereby, to the signal) of any other. Particularly relevant examples of specialized systems functioning in a nondirectional environment are the auditory and visual systems of animals. While both of these mechanisms function in the same environment--filled with sound and light waves--the ears respond to sounds but are deaf to light while the eyes perceive light but are blind to sounds. One can imagine a

similar principle to holds for the neural network. In other words, it is possible that neuronal elements interact, not merely because source elements are connected or have the addresses (or phone numbers) of target elements, but because the elements themselves are uniquely specialized. This specialization permits target elements to "hear" impulse patterns that spread, like sound waves, throughout the neural network if those patterns happen to be signals in their "language." We believe this shift of "responsibility" from source units to target units solves the problem of address. Thus, in this particular sense, the act of communication is more like a (radio) broadcast than a (phone) call because in a broadcast the source unit emits the signal indiscriminately whereas in a phone call a decision must be made as to who is going to receive the call and the phone number of the target unit must be known.

The assumption of non-directional communication among neuronal elements critically depends on the nature of localization and distribution in the nervous system. By localization we mean that specialized elements that are functionally highly selective are fixed with respect to their physical location. Distribution, on the other hand, means that the elements that are simultaneously functioning can be physically widely spread apart. Thus, not only does the nondirectional hypothesis solve the problem of address but it also resolves the apparent incompatibility between localization and distribution. Early distributed models were explicitly nonlocalizationist. Lashley's (1950) original formulation of distribution stated that "the same neurons which retain the memory

traces of one experience must also participate in countless other activities" (p. 479). Somehow every neuron learned (or stored) everything that many other neurons learned. Nonlocalized storage is also an assumption in holographic models of distributed memory (Pribram, 1981; Wess & Roder, 1977). However, evidence gathered by Hubel and Wiesel (1959; 1962, 1965) and others has shown that the brain is not a homogeneous mass. Whereas traditional models of distributed memory considered localization and distribution to be antithetical, more recent evidence suggests that distribution and localization are not incompatible (e.g., Freeman, 1975; John & Killam, 1960; John & Schwartz, 1978; Uttal, 1978). For instance, Freeman argued that "the behavior of animals depends both on the properties of neurons and on the ways in which they are functionally connected or interconnected" (Freeman, 1975, p. 4, italics added). Similarly, Uttal (1978) pointed out that while one must "emphasize the concept of interacting systems and the premise of nonunique localization of each psychological function . . . it also appears that there is a considerable degree of differentiation of function of the various areas of the brain and the brain stem; that is, they are not equipotential" (p. 354). Variable functional relations among interacting systems can be accommodated by a system consisting of specialized units that can communicate in terms of a nondirectional, all-spreading environment.

We have hypothesized an all-spreading medium in order to clarify, at least conceptually, the problem of interaction-at-a-distance in a mass action system with distributed elements. An

all-spreading environment, however, does not mean that electrical or chemical conductance takes place in a vacuum, even though some sort of extracellular propagation may play an important role (see Nicholson, 1979). Neither does it mean nonspecificity or imprecision in the pattern of actual neural connections. The neural network as a whole may serve as a common network.

The two types of physical relational vehicles (directional and non-directional) may be illustrated by an analogy to the functioning of exocrine and endocrine glandular systems. Exocrine glands (e.g., the salivary glands) release their products into specific ducts which direct them to target organs. These would correspond to directional element-to-element (neuroanatomic) connections. Endocrine glands, on the other hand, secrete their products into the extracellular fluid surrounding capillaries. The hormones they produce enter the blood circulation system, which is itself an all-spreading environment. This makes it possible, for example, for the ACTH released in the anterior pituitary gland, located on the lower surface of the brain, to stimulate (activate) cortical adrenal cells located above the kidneys. It is conceivable, in principle, that a direct point-to-point duct could have been physically available to carry ACTH from the pituitary to the adrenal glands. However, if a tube were to be available from every endocrine gland to its target organ, organisms would become monstrously complex. Instead, ACTH enters the blood circulation system. This, of course, takes the hormone to other irrelevant organs as well (hence, all-spreading and nondirectional), but it is also sure to reach the adrenal cells

which are specialized to get activated by it, because these cells like everything else are connected to the blood circulation network.

The possibility that the nervous system is also, in part, an all-spreading environment analogous to the blood circulation system cannot be ruled out. As early as the, 1920's, Paul Weiss argued against the connectionist view and concluded, based on the then existing evidence, that "the central nervous system and the non-nervous periphery entertain their mutual correspondence by means of some sort of sending-receiving mechanism, specific for each individual muscle." According to this view, the central nervous system is "endowed with the capacity for discharging as many different modes or forms of impulses as there are different muscles in the limb." There is a specific impulse for every muscle receptor. Every muscle receptor, on the other hand, "would possess the power to respond selectively" to its proper impulse. Consequently, if "the central impulses for a limb muscle were circularized in the whole limb" the mechanism of selectivity of function "would ensure that every call be answered by the correct muscle, even though the latter may have been displaced, re-innervated by strange nerves, and prevented from sending informative messages back to the centers" (Weiss, 1936, pp. 511-512). Weiss's resonance principle is no longer generally accepted by developmental neuroscientists, but we believe his ideas concerning indiscriminate synaptic connectivity, successfully challenged by Sperry and his associates (see Attardi & Sperry, 1960, 1963; Meyer & Sperry, 1976), must be distinguished

from his suggestive element-impulse specificity hypothesis, which has yet to be directly tested.

An all-spreading functional environment implies that, regardless of its place of origin in the nervous system, the signal that a given functional pattern generates can stimulate elements that "recognize" it wherever they may be located in the nervous system. There are definite indications that this may be the case. Consider a letter recognition (identification) task. Images ordinarily begin on the retina and presumably stimulate corresponding centers or elements somewhere in the brain. It is conceivable that specific "image-to-center" connections as well as long-term graphemic patterns could mediate recognition. However, recognition need not depend on particular hard-wired connections or on pre-existing long-term associations. Blindfolded subjects are capable of correctly identifying letters "finger-written" on their skin. White, Saunders, Scadden, Bach-Y-Rita, and Collins (1970) used a visual substitution apparatus which converted optical images into tactile displays which blind or blindfolded subjects were able to "see with their skin." It was shown that "subjects are able to perceive certain simple displays . . . almost as soon as they have been introduced" (p. 23) and that with minimal amounts of training they are able "to identify familiar objects and to describe their arrangement in depth" (p. 25).

The hypothesis of functional communication between distinctively specialized neuronal elements also finds support in the evidence that the re-establishment of original functional

relations is possible even after specialized cells are surgically removed from their original site and are regrown at a different part of the body. If a piece of skin is removed from the belly region of a salamander and planted on its back and if, after regeneration, this skin, now on the back, is stimulated, the animal proceeds to scratch its belly, the original site. Such seemingly maladaptive responses, extensively studied by Sperry and others, are often discussed in the light of the nature/nurture issue (see, e.g., Rose, 1976). However, more basic than whether something is innate or acquired is the problem of how it works. One may simply assume that regeneration only connects the pre-specialized skin receptor cells to an all-spreading neural network. There is no need for the re-establishment of particular nerve fibers to wind their path, through some mysterious innate guiding mechanism, all the way to the related central cells. Once specialized receptor cells are merely connected to the neural network (or perhaps to the particular brain region), they can activate the individual target cells through generation of unique energy patterns. The energy patterns, generated by the central cells can, in turn, activate the muscles involved in the scratching of the belly. Because the belly receptor cells function in the same unique fashion regardless of where they are located, and because this functioning is recognized by the related central cells as "belly" stimulation, the animal responds maladaptively. Sperry (e.g., 1943) explained these results "in terms of re-establishment of specific anatomical associations rather than in terms of specific nerve energy and resonance phenomena." But he also emphasized that "the latter possibility is by no means excluded" (p. 47). In fact,

it is still not clear that a resolution between Sperry's directional connectionism and Weiss' element-impulse specificity model has yet been achieved (see Meyer & Sperry, 1976; Sperry, 1966; Wall, 1966; Weiss, 1966). As Wall (1966) argued, "the so-called specificity of neuronal function . . . may mean that specificity of function can be attained without a microscopic determination of the exact morphological structure of some parts of the nervous system" (p. 230).

Given the concept of an all-spreading relational vehicle, the most efficient way of relating the cognitive system and the neuronal system seems to be to assume that (a) the cognitive system is comprised of transient functional relations, and that (b) that post-functional patterns are independent of any isomorphic pre-functional neural associations. Independence of post-functional (mental) relations also resolves Minsky's crossbar problem. As Minsky (1980) put it "if the mechanisms of thought can be divided into specialists that intercommunicate only sparsely, then the crossbar problem may need no general solution. For then, most pairs of agents will have no real need to talk to one another; indeed, since they speak . . . different languages, they could not even understand each other" (p.125). And, to continue the metaphor, if they can understand each other, they will do so regardless of where they are located or whether they are connected directly so long as they can "hear" each other (i.e., so long as they are part of the overall neural network).

Pre-Subjective Foundations of the Schema-of-the-Moment

This section discusses some key assumptions pertaining to the microbiofunctional and macrobiofunctional properties of the brain in an attempt to show how these properties can explain the pre-subjective foundations of the schema-of-the-moment. These assumptions, while speculative in detail, are generally compatible with existing neurophysiological literature bearing on localized and distributed functional properties of the nervous system. For clarity of exposition, we shall not interrupt to substantiate every claim or to discuss the controversies that might be involved. The interested reader is encouraged to consult Freeman (1975, Chapter 1) on the nature of dynamic patterns, Hubel and Wiesel (1980) on localization in the primary visual cortex, Lynch (1980) on distribution of function in the posterior parietal cortex, Selverston (1980) on the central pattern generators underlying rhythmic behavior, O'Keefe and Nadel (1979) on localization of "place-coded" neurons in the hippocampus, Puccetti and Dykes (1978) on the problem of accounting for qualitative differences between subjective experiences of touch, hearing, and vision, and Uttal (1978) on the role of microscopic and macroscopic structures in the formation of dynamic representations.

Are Pre-Existing Long-Term Patterns Necessary?

As we have said, current approaches to cognition and comprehension presuppose the existence of long-term relatively static knowledge representations that underlie cognitive functioning. One motivation for hypothesizing long-term mental

structures is the fact that ideas seem to come to mind (to be recalled, etc.) together, or in relation to one another. It is then assumed that they stay together in some cognitive warehouse, even when they are not operative. Thus, the structural approach maintains that ideas are related before they become active, and that remembering involves activation of static knowledge representations.

By contrast, from the biofunctional perspective, there are no pre-existing mental patterns. Cognitive relations are established only after distributed neuronal elements become active. Like chemical elements, neuronal elements have properties that determine their combinatorial potentials. Only when two or more elements with appropriate combinatorial properties (see the section on types of combinatorial relations below) are in a state of simultaneous functioning do they combine to generate a cognitive pattern. Consider, as another analogy, a collection of colored lightbulbs. When a subset of them is on, a unique pattern of light and color is generated. It does not matter whether individual bulbs are physically connected or when each bulb goes on. The characteristics of the pattern are determined by the participating elements and not by how the bulbs are connected physically or by the history of their participation. A given pattern could result from a long sequence of events in which some bulbs would go on and some would go off. Once some or all of the bulbs go off, the particular pattern no longer exists.

Similarly, a constellation of active neuronal elements generates an idea or concept as the component elements combine into

a biofunctional pattern. This can be illustrated in terms of what might happen when a word like dog is understood after it is heard. Hearing the word activates a constellation of independent neuronal elements. This happens, not because the elements are preconnected as a neuroanatomic pattern, but because the stimulus itself (in this case the pattern of sound waves that reach the ear) has independent signal components that activate each of the independent elements of a constellation--elements that can be physically distributed throughout the brain. Once the elements are active, they combine into a biofunctional pattern and, in doing so, they generate the concept corresponding to the word. This notion can be clarified in terms of another analogy. When a handful of pebbles is thrown into a pond, each pebble hits the water at a different spot and creates a wave pattern. Then, the wave patterns of all the pebbles combine to form a global pattern of waves. This global pattern, which results from the combined effects of the individual pebbles, corresponds to the dynamic pattern created by the active elements of the constellation underlying a concept. The concept will arise in the psychological experience of the moment whenever the particular elements that produce it change their activity, functioning as a coherent combination. It does not matter how each element comes to be active (i.e., one at a time, all at once, etc.) or what causes them to be active (the sight of the word, the sound of the word, a dog, etc.). In fact, according to this view, elements that create a particular concept can come to be active as a result of the combination of elements from two or more unrelated constellations whose corresponding concepts have no apparent relation to one

another. In sum, while in a structural pattern, it is the long-term "relations among elements that counts" (Piaget, 1970, p. 9), for a functional pattern what counts is the elements themselves--their characteristics, how they function, and how they functionally combine.

Neuronal Elements as Biofunctional Microsystems

The model we are proposing places a heavy theoretical burden on the notion of neuronal elements. It is, therefore, necessary to specify exactly what sorts of biofunctional properties these elements should have in order to combine into macroactive structures and in order to generate subjective experiences with sufficient qualitative diversity.

While there is general agreement that mental structures are complex and that they consist of more elementary components, there is less agreement as to what these components, or elements, are. Depending on the situation or level of analysis, theorists have used semantic features, perceptual features, images, ideas, etc. as primitive units of analysis. However, in an approach such as Bartlett's or ours, where it is critical that the elements be capable of combining while remaining, in principle, individualizable, the choice of an appropriate standard element is much more constrained. The biofunctional model assumes that the most elementary theoretical construct is a physically unitary (although not physically elemental) and functionally autonomous microsystem. The assumption that the elements are physically unitary systems means that they are taken to be neurophysiological

"atoms." The assumption that the elements are functionally autonomous is compatible with their being viewed as cognitive "atoms." In other words, we view these elements as being the most elementary biofunctional units in the nervous system and the locus of the link between the mind and the brain.

It is important to point out that our use of the term neuronal element is not meant to imply that single neurons actually represent mental structures. Traditionally, such concepts as pontifical neurons (Fessard, 1954; Sherrington, 1947), cardinal cells (Barlow, 1969), command neurons (Wiersma & Ikeda, 1964), and feature detectors (Hubel & Wiesel, 1980) have been postulated to represent complex psychological patterns. In contrast to these views, we assume that mental structures are "molecular" rather than "atomic"; more than one neuronal element must be involved in the creation of any mental entity. In other words, individual neuronal elements do not represent mental structures (i.e., features, images, etc.); only distributed constellations of them do.

The claim that it is distributed constellations of neurons, and not individual ones, that are responsible for the creation of cognitive structures could be interpreted as meaning that individual neuronal elements are equipotential. This is certainly not our view. Rather, like atoms of particular simple substances, neuronal microsystems are assumed to have unique functional properties. As with chemical elements, these properties constrain the types of combinations in which an element can participate, and they constrain the conditions under which such participation can occur. However,

within these constraints, a particular element can participate in an indefinite number of combinations.

The biofunctional perspective also means that the neurons are not equipotential in the sense used by nonlocalization theorists such as Lashley. While in the biofunctional model, each neuronal element can be considered a "memory," or rather a "potential memory" element, it is not assumed that neurons retain memory traces; in particular it is not necessary to assume that neurons retain memory traces for a large number of experiences and behaviors (Lashley, 1950, p. 479). Such a claim would make the activity of neurons completely dependent on past traces by implying that they could only participate in combinations they already had traces for, and that they would only respond to stimuli for which they had a matching trace. In the biofunctional model, past experiences are re-created because the same constellations of elements recur, not because something is stored in each element. The system is completely generative, creating new experiences entirely through new combinations. At the micro-organizational level, each element is physically located in some area of the brain. However, since the elements can functionally coact or interact at a distance through an all-spreading medium, the system can also be fully distributed.

At the macro-organizational level, the totality of active neuronal elements constitutes a mass action system (Freeman 1975). In recent years, the nature of macroactivity in the nervous system has been the subject of an interesting new theoretical approach derived from the field of dynamics (Freeman, 1975; Katchalsky,

Rowland & Blumenthal, 1974; Prigogine & Nicholis, 1971; Kugler, Kelso & Turvey, 1980). According to this view, macroactive structures are dynamic patterns that (a) consist of discrete elements, (b) are self-organizing, and (c) consume energy to maintain stability (see, e.g., Freeman, 1975). Katchalsky and his colleagues, who pioneered the work in this area, state that one possible consequence of "considering discrete systems embedded in a continuous system would be the subordination of obvious structural discreteness to a functional one: the spatially discrete elements could be brought to functional continuity . . . or the structurally continuous medium to functional (dynamic) discontinuity" (Rowland, reported in Katchalsky, Rowland & Blumenthal 1974, p. 78). Clearly, the biofunctional model is compatible with these views. Rewording the Katchalsky et. al. quotation in terms of the present view: one advantage of considering neuronal microsystems embedded in dynamic macroactive structures that they themselves create would be the subordination of the microsystems to their overall functional organization. A constellation of physically unitary microsystems could be brought to functional continuity or the continuous macroactive organization can be subordinated to the independent functioning of individual microsystems. It seems to us that it was shifts of this sort in the relative subordination of individual components to the global structure and vice versa, that Bartlett (1932) deemed necessary in mental functioning when he argued that not only must individual elements combine into an organized mass but that after they do, they must once again be individualizable in the context of the global structure.

Microsystems as Elementary Loci of Psychological Qualities

It seems to us that the key to bridging the gap between cognitive psychology and the neurosciences lies in the specification of the manner in which the nervous system might generate qualitatively diverse psychological experiences. Concern for this problem does not seem to be a characteristic of current practice in cognitive psychology, which tends to focus on unconscious mental structures and processes. However, there has been some concern with this issue in the neurosciences (see e.g., Eccles, 1953; Sperry, 1952, 1969, 1977). Recently, the problem has been brought into sharp focus by Puccetti and Dykes (1978) who emphasized the apparent structural (cytotechtonic) similarity of the primary visual, auditory, and somesthetic sensory areas. Noting that these similarities afford little opportunity for explaining differences in subjective quality, they concluded that "not only is present-day neuroscience unable to account for the subjective differences [between vision, hearing, and touch] in terms of discrete neural mechanisms, but there is no good indication that it ever will be able to do so" (p. 337). While some of the commentators did not find Puccetti and Dykes' conclusions very convincing, others agreed with their assessment of the state of the art. For example, Szentagothai (1978) went so far as to say that "the spectacular developments in the last quarter of a century . . . have widened . . . the gulf between the brain and the mind" (p. 367).

Our views on subjective quality are in general agreement with those advanced over the years by Sperry (e.g., 1952, 1976, 1977),

who claimed (a) that subjective qualities emerge from the activity of the brain, and (b) that these qualities, in turn, exert a causal influence on brain activity. However, in searching for an appropriate level of analysis to explain the causes of subjective qualities, Sperry (1978) excluded the microbiofunctional level and argued that "it is our bet that [the proper level] is not at the atomic, molecular, cellular, or nerve-relay levels, nor even at the sensory cortical levels, but rather at a somewhat higher level that involves . . . centralized adjustments of the brain as a unit" (p. 366). In this respect, we disagree with Sperry. While Sperry's theory might account for the undifferentiated conscious experience (i.e., global awareness), we believe it fails to explain finer qualitative discriminations (i.e., focal awareness). By fixing the locus of subjective quality at the level of neuronal microsystems, the biofunctional model can not only account for people's competence in making fine subjective discriminations (by individualizing components of the whole), but can also explain global differences in subjective experiences (because microsystems can combine into macrobiofunctional organizations that involve the activity of the entire brain).

In order to demonstrate how psychological qualities can arise as a consequence of macroactivity in distributed constellations of elements, we must take a closer look at the key concepts of specialization, constellation, and combination. In order to understand what we mean by element specialization, it may be helpful to again use the lightbulb analogy. Let us suppose that our array

of lightbulbs contains two broad categories of bulbs, namely, colored and uncolored ones. We will call the colored bulbs "specialized elements." The uncolored bulbs we will call "raw elements," implying that they can become specialized by getting painted a particular color. In this array, each bulb can "perform" a few feats always in the same unique fashion: it can go on or off, it can become brighter or dimmer, and if it is not already specialized it can become so. Similarly (and now we are out of the analogy), the neuronal network can be assumed to consist of a great number of elements, each of which is or can become specialized and each of which can get activated or inhibited. In addition, each specialized element can (a) change its rate of activity, (b) produce a unique pattern of energy (i.e., a signal), (c) initiate functioning consistently in the presence of some unique pattern of internal or external energy (i.e., a signal), and (d) generate, when functioning, a unique feeling of awareness. In this sense, a specialized element is a discrete unit with quite specific but very limited properties. This assumption is consistent with the view that "neurons, in the course of differentiation and development and in processing of information over the span of the organism's lifetime, develop unique identities: genetically and experientially determined individualities" (Schmitt, 1970, p. 208), and it is also consistent with the evidence that the relative number of highly specific cells seems to vary drastically with experience (Imbert & Buisseret, 1975).

When two or more specialized elements function simultaneously they can combine to create a macroactive organization or combination (see the section on types of combinatorial relations below). To emphasize the physical distribution of elements participating in a combination, we refer to the physical counterpart of a combination as a constellation. Constellations differ from elements in several respects. First, unlike elements, they cannot be considered specialized. This is because they contain autonomous elements which can participate in other constellations. Second, elements are assumed to be localized and physically unitary while constellations can have elements scattered throughout the nervous system. Third, while individual elements possess element-specific biofunctional properties that theoretically are unambiguously traceable to some unitary physical entity--the element itself, constellations have nonspecific (i.e., emergent) properties which result from the functional combination of the elements involved and which cannot be traced to any unitary physical entity because they are different from those possessed by any one of the participating elements.

The notion of combination encompasses four major biofunctional aspects that result from the activity of the corresponding constellation. First, combination is the establishment of a transient dynamic pattern involving anatomically distributed elements--the combinatorial aspect. Second, combination involves the merging of element-specific energy patterns resulting in nonspecific (i.e., emergent) energy patterns (i.e., signals)--the relational aspect. In the case of energy, pattern combinations can

be conceptualized in terms of interference patterns (Lashley 1950). Third, combination involves blending of element-specific awareness patterns into emergent awareness patterns--the qualitative aspect. Finally, combination involves the merging of element-specific activity into a global intensity dimension--the quantitative aspect. Thus, not only does the biofunctional approach specify how "potential memory" elements (i.e., the microsystems) might be distributed but it also implies that these elements are distributed loci of potential subjective qualities.

It appears, therefore, that the concepts of specialization, constellation, and combination can provide a foundation in terms of which one can account for the origination of psychological quality within the biofunctional model. However, a fuller understanding of this account requires an examination of three specific issues. The first of these, discussed in the next section, pertains to the physical locus of subjective qualities. The second, has to do with the kinds of constraints that exist on possible combinations, and the third is concerned with singling out the activity of components of combinations.

Localization and Distribution of Subjective Qualities

As already mentioned, the relationship between brain hardware and subjective qualities has received a provocative treatment in Puccetti and Dykes (1978) and the associated commentaries. Puccetti and Dykes started by pointing out that vision and hearing, for instance, are qualitatively different subjective experiences. They then assumed that if subjective qualities are localized in the

brain, one would expect to find corresponding differences in the physical structure of those areas of the brain ordinarily associated with vision and hearing. However, in reviewing the relevant evidence, they could find no support for such structural differences, and concluded that perhaps dualism was the only way out of the dilemma. Sperry (1978), on the other hand, questioned the validity of Puccetti and Dykes' assumption and argued that qualitative differences need not be reflected in "activity in the primary sensory fields of the cortex" (p. 366). Rather, they can emerge from the activity of the brain as a whole. Like Puccetti and Dykes, we assume that differences in psychological quality presuppose differences at the neuronal level, even though we disagree with their corollary assumption that qualitative differences must be evident in the anatomic structure of various brain areas. Rather, we assume that different brain areas differ in biofunctional properties and not necessarily in cytostructural characteristics. We also question Sperry's, and Puccetti and Dykes's, claim that the causal loci of subjective qualities cannot exist in particular areas of the brain. In fact, a major goal of the biofunctional theory is to explain differences in subjective quality in terms of microbiofunctional properties of brain areas. According to this view, differences must still exist even if they are not evident in the cytoarchitectural make up of brain tissue.

In terms of the biofunctional model, the solution to the problem of the locus of psychological quality lies in distinguishing between two types of localization. An important implication of

Puccetti and Dykes' argument is that it suggests the need for just such a distinction. Localization ordinarily refers to the physical locus of qualitatively complex psychological phenomena (e.g., semantic features, concepts, the self), or to the physical locus of mechanisms that deal with qualitatively complex input (e.g, short-term memory, pattern analyzers, etc.). Puccetti and Dykes's approach, on the other hand, suggests that localization occurs according to qualitatively similar inputs (i.e., visual and auditory) or qualitatively similar subjective experiences (e.g., visual imagery and auditory imagery). It is this type of localization that is compatible with the notion of distribution discussed earlier. Neuronal elements are localized in particular areas of the brain according to their qualitative functional affinities, elements with similar qualitative properties (e.g., those generating spatial qualities) tend to be physically close together and those with dissimilar qualitative properties (i.e., spatial vs. affective elements) tend to be removed from one another. In other words, the biofunctional theory implies that, in principle, at the microbiofunctional (i.e., elemental) level, quality is homogeneously localized. At the macrobiofunctional level, on the other hand, constellating elements that generate complex and varied conceptual categories cannot form physically localized groups. It appears that at this level the complex nature of mental categories and functions necessarily requires heterogeneous distribution.

A clearer illustration of localization according to biofunctional affinities of neuronal elements can be found in the

work of O'Keefe and Nadel (1978, 1979) on localization of function in the hippocampus. These authors have postulated that in order to find their way around an environment, organisms make use of two partially independent systems called the locale and the taxon systems. The locale system, containing (qualitatively homogeneous) "place-coded" neurons, is responsible for the generation of absolute, nonegocentric, spatial maps. This cognitive mapping system, they claimed, is localized in the hippocampus. The taxon system, on the other hand, is responsible for (qualitatively heterogeneous) taxonomic or categorical information, comprises the rest of the brain, and consists of a number of separate subsystems. O'Keefe and Nadel's approach may be contrasted with that of Olton, Becker and Handelmann (1979) who have argued that the hippocampus is the seat of the working memory. These two approaches to localization are based on very different beliefs about the functional properties of the brain. O'Keefe and Nadel's approach is consistent with the biofunctional model in that it implies that place-neurons, as a qualitatively homogeneous class, form a localized biofunctional set.

Types of Combinatorial Relations

A system comprising a large number of partially-independent subsystems must possess combinatorial properties so that coactivation (or interaction) among the subsystems is possible. For instance, it can be assumed that only a subset of elements within each brain subsystem and throughout the entire mass action system, constellate and reconstellate from moment to moment. Given that

neuronal elements are specialized, and given the assumption that they can interact at a distance, it is possible to consider biofunctional relations among distributed elements independently of the actual neuroanatomic connections.

To characterize the combinatorial relations (i.e. potentials) of neuronal elements, we adopt a system of relations that was postulated for somewhat different purposes by Festinger (1957). In Festinger's system, three types of relations were assumed to exist among cognitions (cognitive units): consonance, dissonance, and irrelevance. According to Festinger, cognitions X and Y are consonant if one follows from the other. When two cognitions have nothing to do with each other, the relation is irrelevance. And, finally, two elements are in a dissonant relation, "if considering these two alone, the obverse of one element would follow from the other" (p. 13).

Festinger's system of relations can be re-conceptualized as dynamic combinatorial properties of neuronal elements, rather than as relations among complex mental units. Recall that an important consequence of element specialization is that neuronal elements can generate characteristic energy (or interference) patterns that provide the necessary and sufficient conditions (i.e., the signals) for the activation of other elements. This means that the functional relation between any two elements does not require that they be connected to one another directly. Rather, in the same fashion that square-dancers respond to the sound pattern in the air, which is, loosely speaking, a "complementary combination" of the

sound patterns generated by the voice of the caller and that generated by the music, the neuronal elements also "dance" to the "sound" of the dominant interference pattern of the moment that spreads indiscriminately through the neural network. The difference is that in the case of the neuronal elements these microsystems are each simultaneously a caller, a musician, and a dancer--it is a caller/musician/dancer. Consider, for instance, three elements, A, B, and C. Suppose that element A is specialized to generate a unique energy pattern, E(A). Element B is specialized to get activated in the presence of E(A); and both A and B are specialized to coact (i.e., engage, for instance, in synchronous rhythmic activity) in the presence of E(AB), where E(AB) is a consonant (or complementary) combination of E(A) and E(B). This means that functionally E(AB) = E(A) = E(B), in much the same way as when different instruments playing in unison are producing the same tune, both individually and as a group. To continue the analogy, when B gets activated it joins the band, and adopts the tune of the moment. In this sense, there is an A-to-B consonant activity initiation relationship and an A-B synchronous coactivation relationship. On the other hand, specialization of elements other than B would be such that they could not "hear" E(A) or E(AB). This would mean an A-to-NON-B irrelevant biofunctional relationship. Similarly, a C-to-B activation-inhibition consonant relationship might imply a C-to-NON-B irrelevant biofunctional relation.

Now suppose that A and C are active at the same time. E(A) will tend to activate B while E(C) will tend to inhibit it. This

would constitute a dissonant biofunctional relation among A, B, and C as a constellation. Such dissonance would cause a momentary state of dissolution, by purturbing the prevailing interference pattern (hence, tending to change its nature from signal to noise), rendering it ineffective, and thereby breaking the dynamic combinatorial relations among A, B, C. By analogy, dissonance is caused by participation of individuals who can hear the music but do not know how to call/play/dance with it. Dissonance is caused because these participants continue to engage in activities incompatible with the ongoing tune and so tend to disrupt the operation, locally or globally. Resolution can be achieved if a new interference pattern emerges to support a surviving and/or novel constellation of elements. This can happen if expert dancers begin to ignore the unskilled ones, if unskilled dancers drop out, if new experts join in and act as "tune-translators" for unskilled dancers, or if the unskilled dancers manage to make their own tune predominant, in which case those who now cannot tune-in drop out.

Another aspect of the combinatorial potentials of neuronal elements can be clarified in terms of the analogy to chemical combination. So far we have assumed that neuronal elements combine as long as they are consonant. This might seem to suggest that any number of consonant elements, once active, would combine into a unified whole. However, it appears more appropriate to conceptualize consonant elements as forming complementary sets, in the same way that oxygen and hydrogen form a complementary combinatorial set, when they combine into water. In other words, we

assume that constellations of elements capable of simultaneous activity in the context of particular interference patterns form complementary or coherence sets such that in a particular instance, if some elements are not yet active the constellation will remain incomplete. Once all the elements come to be active, the set (and the macroactive structure) reaches closure. According to this view, irrelevant elements are defined by their inability to join the active coherence set of the moment when they get activated. Dissonant elements, on the other hand, can join in, but unlike consonant elements, they tend to dissolve or disintegrate the active pattern by disrupting the prevailing interference pattern. It should be evident that irrelevance is a biofunctional relation that is different from consonance or dissonance because it does not by itself affect the functioning of macroactive patterns. It is possible, therefore, to consider the quality of activity in the nervous system as a dichotomous factor (consonance versus dissonance) as opposed to a trichotomous one (consonance versus dissonance versus irrelevance).

Simultaneous and Independent Functioning

The notion of consonance provides a way of conceptualizing how constellations of neuronal elements that are physically distributed across many brain subsystems can combine via simultaneous (rhythmic) activity. However, if consonant activity were restricted to simultaneous activity, the biofunctional system would not work. Simultaneous activity tends to unify all consonant elements in the mass action system into a global combination. As mentioned earlier,

in biofunctional combinations, like in chemical combinations, individual components (i.e., elements or constellations localized within particular subsystems) tend to lose their qualitative individualistic properties as they become part of the larger combination. However, since the activity of the individual components always occurs in the context of the mass action system and never in isolation, it follows that these components should be unable to manifest their individual qualitative properties. Therefore, a system allowing only simultaneous activity would be capable of manifesting only global subjective experiences but would be unable to manifest localized (or finer) qualitative experiences. It was perhaps for this reason that Bartlett (1932) postulated that people must have a way of "turning round upon" their schema-of-the-moment so as to individualize its components.

In order to deal with the problem of component individualization in the context of the mass action system, we believe a second type of consonant functioning must be postulated which we refer to as component independent functioning. Independent functioning of a component of a larger combination occurs if the component changes its rate of activity in relation to that of the combination as a whole. When a component does this, it manifests its individualistic qualitative properties. In terms of the light constellation analogy, when a constellation of lightbulbs is on, it generates a global pattern of light. A bulb, or a subconstellation of bulbs, can be said to function independently if it becomes brighter or dimmer than the rest of the bulbs in the constellation.

At the time that the subconstellation is doing this, its characteristic pattern of light (or color) becomes more evident.

It must be noted that any element or any consonant constellation of elements in the mass action system is, in principle, capable of functioning independently. It must also be noted that in a system of the type proposed here (i.e., one that is exclusively comprised of physically distributed and functionally autonomous elements without containing all-purpose executors or homunculi), independent functioning is the only possible mechanism of component individualization. Thus, the present account, while claiming that the system is homunculus-free, does not specify how individual components come to function independently without a homunculus. However, the biofunctional model does transform the homunculus problem into the more concrete question of how components of the mass action system come to function independently. Clearly, it is conceivable, in terms of the lightbulb analogy, that in a constellation of burning bulbs a subconstellation of them manifests its particular characteristics by growing momentarily brighter or dimmer, that is, by functioning independently of the rest of the larger constellation. More difficult is the question of why this should happen. Presumably, the bulbs do not change their brightness spontaneously--"at will." They cannot manifest spontaneous initiation of activity. But organismic subsystems appear to manifest initiation of spontaneous (or "willful") activity. In other words, organisms are somehow capable of exerting control over organismic subsystems that comprise them (e.g., their limbs). The

biofunctional model implies that this control does not take place because of the control exerted by some single all-purpose homunculus embedded somewhere in the system that is somehow capable of controlling other qualitatively diverse subsystems. Rather, spontaneous control is possible because of the influence of multiple causes all of which, however, exert their influence in terms of component independent functioning. While this way of viewing apparently spontaneous initiation of organismic activity concretizes the problem, our intuitions as to the cause of spontaneous independent functioning of components add little to those of Bartlett. Bartlett (1932) believed that the problem of component individualization was unanswerable at the time but he insisted that it had to somehow occur. He also maintained that whatever form a satisfactory answer to the problem turned out to take, subjective determination (i.e, awareness mediation) would have to be involved (see Iran-Nejad, 1980; Iran-Nejad & Ortony, 1982). One way in which awareness-mediated component independent functioning might work can be illustrated by considering the tip-of-the-tongue phenomenon. Perhaps this phenomenon occurs when a person is implicitly aware of a particular component of the mass action system but is not sufficiently so to make it function independently and, thereby, explicit. There are also more automatic instances of component independent functioning. For example, independent functioning can occur in direct response to external energy patterns, as when one looks at a flashing light or when one encounters surprising information.

In addition to individualization, component independent functioning serves two other basic functions. First, it is an awareness-enhancing mechanism. This is, of course, a restatement of an earlier claim that when a component functions independently, it manifests its characteristic qualitative properties. Secondly, independent functioning is an attention mechanism; that is, an independently functioning component becomes the center of focal attention for the duration that it is functioning independently. Thus, according to the functional theory, component individualization, awareness, and attention are mediated by a single mechanism--component independent functioning.

It is possible that the two types of consonant functioning postulated here--independent and simultaneous--are responsible for the two types of brain wave activity often observed in EEG records. One type of brain wave, the synchronized slow electrical activity, is more evident when the cortex is relatively idle. Since these slow electrical rhythms also occur during slow-wave sleep, many investigators have concluded that synchronizing activity is totally passive, that slow electrical activity is only epiphenomenal to the activity of the brain, and that no active synchronization is involved in psychological functioning. On the other hand, psychological activity has been assumed to occur when slow-waves are less evident and when desynchronized activation becomes prominent (see, e.g., Jasper, 1981). In terms of the biofunctional theory, it may be argued that slow-wave synchronizing activation occurs as a result of simultaneous functioning, and that desynchronized

electrical activity occurs as a consequence of component independent functioning.

The Schema-of-the-Moment: Principal Characteristics and Functions

We have now specified the biofunctional properties of neuronal microsystems, how they are physically distributed, how they intercommunicate, how they generate psychological qualities, and how they engage in simultaneous or independent functioning. We have characterized the neuronal system as a dynamic mass action system consisting of a large population of specialized neuronal elements which can combine in activity to form functional constellations. We have proposed that specialized neuronal microsystems, as elementary loci of subjective qualities, constitute the basis not only for distributed (potential) memory, but also for distributed awareness and distributed attention. Simultaneous functioning was proposed as the mechanism for both implicit and global awareness, as well as for broad attention. Component independent functioning, on the other hand, was postulated as a mechanism for focal awareness and focal attention.

With these concepts, it is now possible to present a rather explicit account of the schema-of-the-moment, which is, loosely speaking, the subjective counterpart of the activity in the mass action system. In this section we shall discuss the main characteristics of the schema-of-the-moment. In particular, we will discuss the stability of different components of the schema-of-the-moment and its overall continuity; we will argue that the organizing forces of the schema-of-the-moment are content-based rather than

structure-based, and we will try to specify the nature of changes that occur in the schema-of-the-moment in response to incoming information. Since we believe that our concept of the schema-of-the-moment is similar to that suggested by Bartlett (1932), much of our discussion will involve elaborations or clarifications of his ideas.

Stability and Continuity

The schema-of-the-moment is a constantly changing phenomenon involving both global and focal experiences. With respect to stability and change, the totality of the schema-of-the-moment may be viewed as comprising three theoretically distinguishable, but not actually separate, components. We will refer to these as the background component of the schema-of-the-moment (Background-SOM), the dominant component of the schema-of-the-moment (Dominant-SOM), and the independently functioning component of the schema-of-the-moment (Independently-Functioning-SOM). The Background-SOM is a slowly-functioning loosely-integrated component in which elements with consonant, dissonant, and irrelevant functional properties can coexist. It involves the major portion of the schema-of-the-moment and the majority of the elements in the mass action system. Because of the slow rate of activity in the Background-SOM, it remains the closest component to the microbiofunctional level. This is because at low levels of activity, there is less functional integration and, consequently, the active elements will tend to preserve their localized individualistic functional properties. This component is responsible for the background or peripheral awareness of such

things as time, space, self, and various other "active" content domains. The background-SOM is ordinarily a stable component of the schema-of-the-moment and most of its elements maintain an activity rhythm that can last for hours, weeks, months, or even years without undergoing significant change. Major shifts in this component, however, do occur especially during landmark occasions such as unusual personal successes or failures, personal tragedies, and, to some extent, during less dramatic changes in normal life patterns such as travel and vacations. More subtle changes in the Background-SOM occur as a function of interaction with other components of the schema-of-the-moment. The Background-SOM remains stable to the extent that its elements fail to participate, because of their irrelevance, in other components of the schema-of-the-moment.

The second major component, the Dominant-SOM, results from simultaneous macroactivity in consonant elements of the moment. This component depends for stability on its incompleteness and, occasionally, on rehearsal. More specifically, an incomplete schema tends to remain dominant longer than a complete one, because an incomplete schema remains active through development while a complete schema can remain dominant merely through effortful rehearsal. A person is only globally aware of activity in the Dominant-SOM and has only implicit awareness of its components. With respect to the nature of ongoing activity, the Dominant-SOM may be either <u>resolving</u> or <u>dissolving</u>. A resolving Dominant-SOM consists of an incomplete set of consonant elements and tends to

remain active until closure is reached through element enrichment (i.e., through activation of other consonant members of the coherence set), after which time it can only remain dominant through rehearsal. A dissolving Dominant-SOM consists of consonant and dissonant elements and tends toward resolution through disintegration. A dissolving Dominant-SOM may end up in total disintegration through what might be called element shedding (i.e., the loss of active consonant elements). Element shedding may also result in partial disintegration when "dissonance-infected" consonant elements drop out until no such elements are involved, at which time the remaining consonant elements may initiate a resolving Dominant-SOM. Experientially, resolving Dominant-SOM activity manifests itself as feelings of consistency, curiosity, suspense, understanding, interestingness, and closure. Dissolving Dominant-SOM activity, on the other hand, gives rise to experiences of conflict, fear, anxiety, confusion, aversion, and lack of closure.

The third major component is the independently functioning schema-of-the-moment, Independently-Functioning-SOM. This is the most transitory component of the schema-of-the-moment, since it soon joins either the Dominant-SOM, if it is consonant or dissonant with it, or the Background-SOM, if it is irrelevant to the Dominant-SOM.

This tripartite characterization of the schema-of-the-moment is not meant to suggest that the three components are actually distinct. First, the initial creation of the Dominant-SOM occurs when some elements in the Background-SOM come to function independently, under the influence of external stimulation, for

instance. Subsequently, the Background-SOM serves as the context for the development of the Dominant-SOM and as the only source of element enrichment for it. Subsequent Dominant-SOM enrichment is mediated by the activity of the Independently-Functioning-SOM. It occurs when elements in the Background-SOM consonant with those in the Dominant-SOM come to function independently, either as a result of changes in the external stimulation, or as a result of changes in the internal relational environment which is, in turn, caused by the activity in Dominant-SOM. In this way, the three components of the schema-of-the-moment continue to interact and to create the constantly changing phenomenal experience of the moment. So, if the biofunctional model is correct, there are no individual mental entities--there are no cognitive building blocks. There is total continuity, not only with the immediate external or internal context, but also in time, in space, and with respect to personal history. In spite of this total continuity, it is often possible to single out particular components of the schema-of-the-moment. But, even when focussing on a single "distant" component, the continuity is never lost. A quick excursion to a remote childhood experience does not destroy the experience of the moment. It seems that it is always the past that "visits" the present (by getting re-created when the conditions are suitable) and not the present that searches for the past. Transitions are almost always smooth and continuous.

The Primacy of Content over Structure

Even though we claim that there exist no long-term static structures in the head, we still have to explain the origin of

transient structures. Our explanation here is essentially the same as Bartlett's (1932), although Bartlett did not make his theory very explicit. In the model we are proposing, neuronal microsystems are the biofunctional generators of primitive psychological qualities. At a slightly less biological level, Bartlett (1932) referred to these primitive qualities as "images" (including what he called percepts, appetites, instincts, ideals), and claimed that images are the basic ingredients of the schema-of-the-moment. According to functional models of this sort, the only type of structure that can exist is the structure of organized content--structure cannot exist independently of content (Shanklin, 1981). Thus, if our interpretation of Bartlett is correct, his functional schema theory is very different from the kinds of structural schema theories that it has spawned. Structural theories are based on the assumption that relatively content-free abstract structures serve to organize content. Bartlett's theory, on the other hand, seems to suggest that content possesses intrinsic organizing properties that constantly produce and reproduce structure thus eliminating the need to postulate abstract organizing structures. Furthermore, while in his theory, Bartlett stressed that schema bias, or "determination by schemata" as he called it, is a critical factor in cognitive functioning, he also insisted that there is an even more potent bias, namely, the bias inherent in the qualitative properties of specific content elements. Element bias is more potent because, for instance, it makes it possible to skip directly to events that occurred in the remote past despite the determinism of the current schema-of-the-moment:

> In the experiments on perceiving, or imaging, and on all the various modes of recall, while there was a sense in which subjects could accurately be said to have reacted to whatever material was presented 'as a whole,' yet in that whole some special features were invariably dominant. In many cases, when the material had to be dealt with at a distance, as in remembering, the dominant features were the first to appear, either in image form, or descriptively through the use of language. In fact, this is one of the great functions of images in mental life: to pick items out of 'schemata,' and to rid the organism of over-determination by the last preceding member of a given series. (p. 209)

Bartlett illustrated how the reappearance of some key content elements enabled one of his subjects to remember a story after more than ten years. Bartlett maintained that remembering begins with a global impression built around a few dominant details from the original experience, an impression which is primarily of the nature of affective quality. After the establishment of this global impression comes the immediate return of other details that may contain "some inventions and transformations, [but] seem clearly to be derived from some of the events of the original story" (p. 209). Bartlett maintained that in any learning or remembering situation, the "dominant, or over-weighted, elements [that] stand out from the rest ... together with their determining tendencies, are apt to set the meaning of that situation" (p. 234). Thus, according to Bartlett, the qualitative properties of a few content elements cause

a global impression that sets the stage for the recall of past experiences.

Similarly, the biofunctional model assumes that at the most primitive level content elements are created by neuronal elements. When a subconstellation of neuronal elements representative of those that were active at the time of the original experience get activated (e.g., as a function of the stimuli provided by seeing and talking to an experimenter and by the recall probes provided), it generates element-specific awareness patterns that combine to create the global impression. The elements also generate element-specific energy patterns that combine to create the relational environment that existed at the time the material was originally learned. The relational environment then sets the stage for the activation of other consonant elements that enrich the global impression. The result is a schema-of-the-moment that approximates an earlier experience.

The square-dancing analogy used earlier can illustrate how this might happen. Recall that individual neuronal elements were likened to individual square-dancers with the difference that neuronal elements not only served as dancers but, at the same time, as caller/musicians. One can imagine how a few caller/musician/dancers might initiate a performance in a large crowd. Soon the sound of their music pervades the air and more and more individuals join in. Similarly, once they come to be active, a few neuronal elements that participated in an earlier experience can re-create a relational environment (a tune) uniquely representative of that experience.

Acquiring New Information: Combination or Slot Filling

One of the most widely studied aspects of conventional schema theories is the slot filling thesis. According to this, a schema is an abstract frame that contains slots which are filled by incoming schema-related information. A corollary of the slot filling thesis is that people only learn what they have schemata for and ignore everything else (Neisser, 1976). The thesis has trouble with the fact that people can and do remember incongruous information (see, Schallert, 1982; Thorndyke & Yekovich, 1980).

It must be acknowledged that there have been attempts to deal with the processing and recall of incongruous information within conventional schema theories (see e.g., Schank & Abelson, 1977 and Schank, 1982 on expectation failures). One approach, studied extensively by Graesser and his associates (Graesser, 1981; Graesser, Gordon & Sawyer, 1979; Graesser, Woll, Kowalski & Smith, 1980; Smith & Graesser, 1981; Woll & Graesser, 1982) defines schema-relatedness in terms of typicality--the more typical an item of information the more likely it is to be in the schema. To the extent that an item is schema-atypical, it is to be considered unrelated or incongruous. In this approach, an atypical item is recalled because at the time of learning it is indexed as such, that is, it "is encoded with a distinctive, unique tag and stored as a separate unit" (Woll & Graesser, 1982, p. 290).

Even if salvaged through some kind of indexing scheme, the slot filling thesis suffers, we think, from another problem related to the fact that it implies that new information or content fills the

slots provided by the schema passively. However, if the biofunctional model is correct in claiming that content elements possess their own functional properties, then these elements must play an active combinatorial role. In fact, the claim that content elements exert their own "active biases" was one of the recurrent themes in Bartlett's theory. He argued that the "active biases" caused by new incoming information play a dominant role in the comprehension of both congruous and incongruous information. Furthermore, Bartlett cautioned against a passive slot filling interpretation of his theory:

> The process is not merely a question of relating the newly presented material to old acquirements of knowledge. Primarily, it depends upon the active bias, or special reaction tendencies, that are awakened in the observer by the new material, and it is these tendencies which then set the new into relation to the old. To speak as if what is accepted and given a place in mental life is always simply a question of what fits into already formed apperception systems is to miss the obvious point that the process of fitting is an active process. (p. 85)

For Bartlett, therefore, incoming information does not passively fill slots that are made available by the operative schema. Rather, it is the potential of the new information to awaken qualitative "active biases" that sets "the new into relation to the old." In other words, what is newly acquired actively combines with what is old. The word active must be interpreted with

caution here. It means that what is "awakened" by the new information does not surrender itself passively to the shackles of an active schema. Rather, the new information imposes "active biases" of its own that often override the biases imposed by the schema-of-the-moment, as when incongruous information spontaneously draws attention away from the operative schema. Furthermore, if our interpretation of Bartlett is correct, in his theory, and certainly in the biofunctional model presented here, the potential for content elements to play an active role exists after learning as much as it does at the time of learning. In other words, being functionally autonomous, these elements do not remain chained passively to a structure after they combine with it until that structure is reactivated, any more than dancers freeze into a "solid" frame as soon as the tune to which they are dancing stops. Being autonomous individuals, each dancer can participate in a different activity in the meantime. Dynamic combination is not a long-term bond. It is some sort of momentary cooperative activity (see Freeman, 1975), a cooperation to create something novel.

Bartlett's observations about the nature of learning and remembering are completely compatible with those implied by the biofunctional model. The biofunctional model explicitly rules out the preservation of static relations and of abstract structures. The only option open, therefore, is to explain remembering in terms of the functional properties of autonomous neuronal elements and not in terms of static mental relations. In the biofunctional model, the only relations that can be preserved are transient functional

relations--active, concrete, and particular functional relations--where active, concrete, and particular mean on-going biological activity in a particular organismic system. As Bartlett put it "what is essential to the whole notion" of a schema is that it is "actively doing something all the time ... [it is] carried along with us, complete, though developing, from moment to moment" (1932, p. 201).

The term transient also needs some qualification. There is a sense in which transient functional relations could last a long time, that is, if the activity involved continues in the manner postulated by Bartlett and specified in this paper. A square dancing session is inherently transient, but it could, in principle, last for days, weeks, or even years. Therefore, if our interpretation of Bartlett is correct, his theory was not based on the preservation of abstract long-term relations underlying generic information, as has been suggested by some authors (see e.g., Woll & Graesser, 1982). On the contrary, he held that every piece of generic or abstract information, or any other complex mental structure, had to be re-created afresh based on the qualitative properties of active elements. What is permanent is the elements themselves (for Bartlett "image-like" content elements and in our model neuronal microsystems). This is probably why Bartlett emphasized the tendency of subjects to preserve the concrete. For instance, he stated that:

> [In folk-tales and] in other types of material, every general opinion, every argument, every piece of reasoning, and every

> deduction, is speedily transformed and then omitted. The greatest efforts in this direction were achieved by subjects who reported a visual method of recall, as if this method carries with it an inevitable bias towards the concrete. The tendency observable in several instances for a narrative, a description, or an argument to take on a personal form, seems to be due in part to the same factor. . . . It may, at first, seem that the mass of folk-proverbs which are traditionally preserved among every people contradicts the tendency toward the concrete. But the strength of the folk-proverbs lies in its applicability to the individual instances. As a mere generality it never would have been preserved and, except in a literary sense, it is practically never used. (pp. 172-173)

Bartlett maintained that acquisition of new information involves two basic functions. First, there is an immediate physiological function made possible by the reaction of a sensory mechanism to external stimuli. This, he believed, is already selective; its selectivity is determined by the qualitative properties of the stimuli involved, and it approximates what is generally meant by hearing, seeing, and so on. The second function has to do with the reaction of the organism as a whole to the immediate physiological pattern of activity. This is also selective but its selectivity is made possible, not by some localized mechanism, but by the global qualitative properties of the active mass of the moment. This, Bartlett maintained, approximates what is generally called listening as opposed to hearing, or looking as

opposed to seeing. Bartlett believed that the type of selectivity that is directly based on "qualitative factors is dominant over any other type in all the higher mental processes" (p., 190). This selectivity makes it possible to gather, from among elements present both in the active sensory pattern or in the active mass of the moment, those elements that are "most relevant to the needs of the moment" and so to construct an updated schema. He maintained that construction is either spontaneous and immediate, or that it is mediated by what he called effort after meaning, effort to relate "what is given to something else" or to understand what is not immediately obvious.

Bartlett's theory can be readily specified in biofunctional terms. According to the biofunctional model, sensory stimulation causes independent functioning of a constellation of neuronal elements and creates a momentary Independently-Functioning-SOM which then interacts with the Dominant-SOM in the following fashion: If the Independently-Functioning-SOM, or a subconstellation of its elements, is consonant with (but not necessarily typical of) the Dominant-SOM, it will combine with it. Those elements in the Independently-Functioning-SOM that are irrelevant to the Dominant-SOM become part of the Background-SOM, even if they happen to be typical of the situation in which the Dominant-SOM is active (e.g., the waitress serving in a restaurent has brown hair). If the Independently-Functioning-SOM, or a subconstellation of its elements, is dissonant with (but not necessarily atypical of) the Dominant-SOM (e.g., long waiting lines are annoying in restaurants),

it will cause a temporary state of dissolution in the Dominant-SOM by causing a purturbation in the internal relational environment and by changing the nature of the energy pattern of the moment from signal to noise. Dissonance is resolved if the Dominant-SOM undergoes spontaneous element enrichment or element shedding. The diners may be relieved to see an acquaintance in the line who is fun to talk to while waiting, or they may give up waiting and go to an otherwise less preferred restaurant. If resolution cannot occur, the dissonant Independently-Functioning-SOM becomes part of the Background-SOM. The diners might decide to wait, move their thoughts to a different topic, but, at the fringe of their awareness, they might still remain troubled by the long wait. Resolution or lack of it is caused by localized element bias effects and by global schema bias effects, both of which are caused by the functional properties of elements and both of which together manifest themselves in terms of effort after meaning.

According to the biofunctional model, therefore, to the extent that the Independently-Functioning-SOM combines with the Dominant-SOM, it will lose its distinctive qualitative characteristics, just as oxygen and hydrogen lose their combustible properties when they combine to form water. This is how the combination hypothesis explains the fact that in recognition memory new items can be difficult to discriminate from similar old items. More specifically, it is impossible to discriminate already integrated

old information from new information that differs from it only by distinctive properties that are lost as a result of the act of combination.

Sources of Functional Initiation

The assumption that long-term static structures do not exist, and the complementary claim that mental relations are established only after neuronal elements are already active, raises the problem of how neuronal elements come to be in a state of functioning to begin with. This problem seems particularly urgent in relation to remembering. If mental structures are transient, how can people remember anything? How can they recall together what they have learned together if they have not stored it together? That these questions appear to be so challenging seems to us to be a reflection of the deep-seatedness of the permanent-storage metaphor, which also seems to be responsible for widespread rejections or misinterpretations of Bartlett's reconstructive theory of remembering (see Iran-Nejad, 1980).

Bartlett (1932) rejected the long-term storage metaphor and proposed that remembering is reconstructive or re-creative. In support of his claim, he showed that recall is often inaccurate. Some researchers (e.g., Zangwill, 1972) have treated reconstruction as if it were equivalent to inaccuracy in recall and have considered the fact that recall is often accurate as evidence against Bartlett's theory. Although Spiro (1977) argued against this interpretation of the notion of reconstruction, authors continue to fail to distinguish between reconstruction and the mere occurrence

of recall errors. For instance, a recent review of research on schema theory concluded that "the consensus is that reconstruction [i.e. as evidenced by the incidence of recall errors] is quite rare and occurs only under special circumstances" (Alba & Hasher, 1983). Several other researchers, on the other hand, have followed Bartlett, as we have, in calling into question the long-term storage metaphor and in maintaining that remembering is re-creative (see, e.g., Bransford et al., 1977; Jenkins, 1977). However, the issue of how accurate recall is possible given only transient functional relations has yet to be resolved.

According to the biofunctional model, in order to demonstrate how recall is possible without long-term storage of static structures, the problem of remembering must be considered in terms of two separate problems, namely, the problem of specifying the sources of functional initiation in neuronal elements, and the problem of specifying what happens following such functional initiation.

The causes of initiation of (or changes in) activity in elements can only be understood by recognizing that the nervous system is a multiple-source dependent system with respect to functional initiation. First, there are endogenous sources of functional initiation that arise within the organism. Endogenous sources may be biological, biofunctional, or mental. That hungry individuals are more likely to seek food has perhaps more to do with biological sources of initiation than with other endogenous sources. While we cannot specify the relative contribution of biological

factors and their interaction with biofunctional, psychological, or environmental sources, the fact that such factors exist is well-established (see, e.g., Colquhoun, 1971). The major biofunctional source of initiation of functioning, according to the present model, might be called the combinatorial source. As elements combine, they create novel energy (or signal) patterns that set the stage for the initiation of functioning in other elements through the establishment of emergent functional relations. There are also more subtle biofunctional sources that play a critical role. A large number of neuronal elements in the Background-SOM are specialized to maintain a particular biofunctional rhythm or cycle. Endogenous sources responsible for awakening organisms from sleep might be largely of this type. The main psychological source of functional initiation in neuronal elements is assumed to be the Dominant-SOM. How the Dominant-SOM acts as a source of initiation of functioning, or whether it is the only component of the schema-of-the-moment through which the mind influences the activity of the brain, is a question that we cannot yet answer.

The final but perhaps the most important source of functional initiation as far as the stability and the development of the schema-of-the-moment are concerned, are exogenous sources--those external energy patterns (or signals) that constantly influence the neuronal system through several independent sense organs. It seems as though nature has found it profitable to relate organisms to the world through more than one sense organ, each serving as an independent source of functional initiation.

The multiplicity of sources of functional initiation means that after initiation of activity, the development of the schema-of-the-moment is not a straightforward combination of functioning elements. Rather, "the complexity of 'schematic' formation means that many objects, many stimuli, many reactions, get organized simultaneously into different cross-streams of organized influences" (Bartlett, 1932, p. 302). Thus, the qualitative characteristics of autonomous elements play a vital role in the re-creation of past experiences and in the creation of new ones. Consequently, after functional initiation, there is a more critical phase in the development of the schema-of-the-moment that must be taken into account. According to the biofunctional model, the nature of activity in this phase is solely determined by the qualitative functional properties of neuronal elements, both at a global level (as manifested in schema bias) and at a local level (manifested in terms of element biases). Earlier, we used the term enrichment to refer to the development toward closure of the Dominant-SOM. However, since multiple-source functioning means activation of dissonant elements, activity in the Dominant-SOM during the enrichment phase, might also be viewed as an act of problem-solving. According to this view, post-initiation enrichment is guided by two basic types of subjective qualities, which are determined by dissonant and consonant biofunctional properties of active neuronal elements and which tend to manifest themselves in terms of what might be called problem recognition and resolution recognition capacities. If the biofunctional theory is correct, problem-solving during recall, and problem-solving in general, must operate toward justification of these two types of

subjective qualities. It is this problem-solving nature of remembering that renders recall inaccurate or accurate, as far as "the actual facts of the learning situation," as Bartlett put it, are concerned, since post-initiation problem-solving makes remembering totally dependent on the Dominant-SOM at the time of recall. Accuracy in recall is determined by the degree to which the actual facts of the recall situation, especially those that serve as the sources of functional initiation, approximate those of the learning situation.

Conclusion

We have attempted to sketch a model of the mind that we hope is compatible with what is known about the brain and the nervous system. Our primary goal has been to address questions relevant to psychology as opposed to artificial intelligence. We have tried to show how cognition is possible in an animate system having the kind of biological constraints that humans have, rather than how cognition might be possible in some more abstract "system-independent" manner. This choice was made because we believe that the nature of human cognition and experience is necessarily determined by the way in which the individual components of the system function.

A second goal was to bridge the gap between cognitive psychology and the neurosciences. To the extent that we have succeeded, the result is a model that strictly speaking does not conform to the standards of either neuroscientific models or of psychological ones. We have drawn upon what we judged to be

relevant literature in both the neurosciences and cognitive psychology. Given the diversity of this literature, and given our own particular goals, it is likely that some of the authors of the ideas we have used will find our approach difficult to accept. In employing the proposals of others, we have taken care to specify clearly those aspects of their work we have found attractive. Thus, for example, our endorsement of Sperry's proposals about consciousness in no way entails a commitment to his general philosophy.

There are doubtless many problems with the model we have proposed, and perhaps with the way we have presented it. We hope that these problems are no more serious that those facing conventional models. On the positive side, we think that a model of the type we have presented might be able to provide a solution to some of the more complex philosophical problems having to do with mental representations discussed, for example, by Dennett (1983). Like Dennett, the central claim we have made is that it is neither necessary nor is it ultimately fruitful to conceive of knowledge representations as stored abstractions upon which various kinds of cognitive processes operate.

In a paper of this kind, it is not possible to do all that one would like. We have resisted trying to propose detailed accounts of the huge range of aspects of mental life--each would take a book. We have also not discussed the empirical consequences of the view we have proposed because that would have necessitated just such detailed discussions of the individual aspects of cognition. We

have preferred to present an impressionistic sketch of our account from which, hopefully, the big picture emerges even if some of the details are absent or do not accurately portray the way things really are.

References

Adams, J. A. (1977). Feedback theory of how joint receptors regulate the timing and positioning of a limb. Psychological Review, 84, 504-523.

Alba, J. W., & Hasher, L. (1983). Is memory schematic? Psychological Bulletin, 93, 203-231.

Attardi, D. G., & Sperry, R. W. (1960). Central routes taken by regenerating optic fibers. Physiologist, 3, 12.

Attardi, D. G., & Sperry, R. W. (1963). Preferential selection of central pathways by regenerating optic fibers. Experimental Neurology, 7, 46-64.

Barlow, H. B. (1969). Pattern recognition and responses of sensory neurons. Annals of the New York Academy of Science, 156, 872.

Bartlett, F. C. (1932). Remembering: A study in experimental and social psychology. Cambridge, England: Cambridge University Press.

Berlin, B., & Kay, P. (1969). Basic color terms: Their universality and evolution. Berkeley: University of California Press.

Bransford, J. D., McCarrell, N. S., Franks, J. J., & Nitsch, K. E. (1977). Toward unexplaining memory. In R. E. Shaw & J. D. Bransford (Eds.), Perceiving, acting, and knowledge: Toward an ecological psychology. Hillsdale, NJ: Erlbaum.

Bransford, J. D., Nitsch, K. E., & Franks, J. J. (1977). Schooling and the facilitation of knowing. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), Schooling and the acquisition of knowledge. Hillsdale, NJ: Erlbaum.

Colquhoun, W. P. (1971). Biological rhythms and human performance. New York: Academic Press.

Dennett, D. (1983, March). Styles of mental representation. Paper presented at the University of Illinois, Urbana-Champaign, IL.

Donchin, E. (1981). Surprise! . . . Surprise? Psychophysiology, 18, 493-513.

Eccles, J. C. (1953). The neurophysiological basis of mind: The principles of neurophysiology. Oxford: Clarendon.

Edelman, G. M. (1978). Group selection and phasic reentrant signaling: A theory of higher brain function. In G. M. Edelman & V. B. Mountcastle (Eds.), The mindful brain. Cambridge: The MIT Press.

Eliashberg, V. (1981). The concept of E-Machine: On brain hardware and the algorithms of thinking. In Proceedings of the Third Annual Conference of the Cognitive Science Society (pp. 289-291). Berkeley, CA.

Fahlman, S. E. (1981). Representing implicit knowledge. In G. H. Hinton & J. A. Anderson (Eds.), Parallel models of associative memory. Hillsdale, NJ: Erlbaum.

Feldman, J. A. (1979). A distributed information processing model of visual memory (Tech. Rep. No. 52). Rochester: University of Rochester, Computer Science Department.

Feldman, J. A. (1981). A connectionist model of visual memory. In G. H. Hinton & J. A. Anderson (Eds.), Parallel models of associative memory. Hillsdale, NJ: Erlbaum.

Fessard, A. E. (1954). Mechanisms of nervous integration and conscious experience. In E. D. Adrian, F. Bremer, & H. Jasper (Eds.), Brain mechanisms and consciousness. Springfield, IL: Thomas.

Festinger, L. (1957). A theory of cognitive dissonance. Stanford, CA: Stanford University Press.

Freeman, W. (1975). Mass action in the nervous system. New York: Academic Press.

Gallistel, C. R. (1980). The organization of action: A new synthesis. Hillsdale, NJ: Erlbaum.

Graesser, A. C. (1981). Prose comprehension beyond the word. New York: Springer-Verlag.

Graesser, A. C., Gordon, S. E., & Sawyer, J. D. (1979). Recognition memory for typical and atypical actions in scripted activities: Tests of a script pointer + tag hypothesis. Journal of Verbal Learning and Verbal Behavior, 18, 319-332.

Graesser, R. C., Woll, S. B., Kowalski, D. J., & Smith, D. A. (1980). Memory for typical and atypical actions is scripted activities. Journal of Experimental Psychology, 6, 503-515.

Grossberg, S. (1982). Studies of Mind and Brain. Boston: D. Reidel.

Head, H. (1920). Studies in neurology (Vols 1-2). London: Frowde.

Hinton, G. H. (1981). Implementing semantic networks in parallel hardware. In G. H. Hinton & J. A. Anderson (Eds.), Parallel models of associative memory, Hillsdale, NJ: Erlbaum.

Hinton, G. H., & Anderson, J. A. (1981). Parallel models of associative memory. Hillsdale, NJ: Erlbaum.

Hubel, D. H., & Wiesel, T. N. (1959). Receptive fields of single neurons in the cat's striate cortex. Journal of Physiology (London), 148, 574-591.

Hubel, D. H., & Wiesel, T. N. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. Journal of Physiology (London), 160, 106-154.

Hubel, D. H., & Wiesel, T. N. (1965). Receptive fields and functional architecture in two non-striate visual areas (18 and, 19) of the cat. Journal of Neurophysiology, 28, 229-289.

Hubel, D. H., & Wiesel, T. N. (1980). Brain mechanisms of vision. In Readings from Scientific American: Mind and behavior. San Francisco: Freeman.

Imbert, M. & Buisseret, Y. (1975). Receptive field characteristics and plastic properties of visual cortical cells in kittens reared with or without visual experience. Experimental Brain Research, 22, 2-36.

Iran-Nejad, A. (1980). The schema: A structural or a functional pattern (Tech. Rep. No. 159). Urbana: University of Illinois, Center for the Study of Reading. (ERIC Document Reproduction Service No. ED 181 449)

Iran-Nejad, A., & Ortony, A. (1982). Cognition: A functional view. (Tech. Rep. No. 231). Urbana: University of Illinois, Center for the Study of Reading. (ERIC Document Reproduction Service No. ED 215 308)

James, W. (1890). Principles of psychology. New York: Holt.

Jasper, H. H. (1981). Problems of relating cellular or modular specificity to cognitive functions: Importance of state-dependent reactions. In Proceedings of a Neurosciences Research Program Colloquium, The organization of the cerebral Cortex. Cambridge: The MIT Press.

Jenkins, J. J. (1977). Remember that old theory of memory? Well, forget it. In R. E. Shaw & J. D. Bransford (Eds.), Perceiving, acting, and knowledge: Toward an ecological psychology. Hillsdale, NJ: Erlbaum.

Jenkins, J. J. (1981). Can we have a fruitful cognitive psychology? In J. H. Flowers (Ed.), Nebraska symposium on motivation, 1980. Lincoln: University of Nebraska Press.

John, E. R. (1967). Mechanisms of memory. New York: Academic Press.

John, E. R. (1972). Switchboard versus statistical theories of learning and memory. Science, 177, 850-864.

John E. R., & Killam, K. F. (1960). Electrophysiological correlates of avoidance conditioning in the cat. Journal of Nervous and Mental Disease, 131, 183.

John, E. R., & Schwartz, E. L. (1978). The neurophysiology of information processing and cognition. Annual Review of Psychology, 29, 1-29.

Katchalsky, A. K., Rowland, V., & Blumenthal, R. (1974). Dynamic patterns of brain cell assemblies. Cambridge, MA: The MIT Press.

Kay, P. (1981). Color perception and the meaning of color words. In Proceedings of the Third Annual Conference of the Cognitive Science Society. Berkeley, CA: 289-291.

Kay, P., & McDaniel, C. K. (1978). The linguistic significance of the meanings of basic color terms. Language, 54, 610-646.

Klatzky, R. L. (1975). Human memory. San Francisco: Freeman.

Kugler, P. N., Kelso, J. A. S., & Turvey, M. T. (1980). On the concept of coordinate structures as dissipative structures. In G. E. Stelmach & J. Requin (Eds.), Turorials in motor behavior, Amsterdam: North-Holland.

Kuhn, T. S. (1970). The structure of scientific revolutions. Chicago: University of Chicago Press.

Lashley, K. S. (1950). In search of the engram. In Symposia of the Society for Experimental Biology, No. 4. Physiological mechanisms in animal behavior. New York: Academic Press.

Lynch, J. C. (1980). The functional organization of posterior parietal association cortex. Behavioral and Brain Sciences, 3, 485-534.

Maturana, H. R. (1978). Biology of language: The epistemology of reality. In G. A. Miller & E. Lenneberg (Eds.), Psychology and biology of language and thought: Essays in honor of Eric Lenneberg. New York: Academic Press.

Meyer, R. L., & Sperry, R. W. (1976). Retinotectal specificity: Chemoaffinity theory. In Neural and behavioral specificity: Studies on the development of behavior and the nervous system (Vol. 3). New York: Academic Press.

Miller, J. (1978). The body in question. New York: Random House.

Minsky, M. (1980) K-lines: A theory of memory. Cognitive Science, 4, 117-133.

Neisser, U. (1976). Cognition and reality. San Francisco: Freeman.

Nicholson, C. (1979). Brain-cell microenvironment as a communication channel. The Neurosciences 457-476.

Norman, D. A. (1980). Twelve issues for cognitive science. Cognitive Science, 4, 1-32.

O'Keefe, J., & Nadel, L. (1978). The hippocampus as a cognitive map. Oxford: Clarendon.

O'Keefe, J., & Nadel, L. (1979). Precis of O'Keefe & Nadel's "The hippocampus as cognitive map." Behavioral and Brain Sciences, 2, 487-533.

Olton, D. S., Becker, J. T., Handelmann, G. E. (1979). Hippocampus, space, and memory. The Behavioral and Brain Sciences, 2, 313-365.

Piaget, J. (1970). Structuralism (C. Maschler, trans.). New York: Harper & Row (originally published, 1968).

Pribram, K. H. (1981). The brain, the telephone, the thermostat, the computer, and the hologram. Cognition and Brain Theory, 4, 105-119.

Prigogine, I., & Nicholis, G. (1971). Biological order, structure and instabilities. Quarterly Review of Biophysics, 4, 107-148.

Puccetti, R., & Dykes, R. D. (1978). Sensory cortex and the mind-brain problem. The Behavioral and Brain Sciences, 3, 337-375.

Pylyshyn, Z. W. (1973). What the mind's eye tells the mind's brain: A critique of mental imagery. Psychological Bulletin, 80, 1-24.

Rose, S. (1976). The conscious brain. New York: Vintage Books.

Schallert, D. L. (1982). The significance of knowledge: A synthesis of research related to schema theory. In W. Otto & S. White (Eds.), Reading expository material. New York: Academic Press.

Schank, R. C. (1982). Dynamic memory: A theory of reminding and learning in computers and people. London: Cambridge.

Schank, R. C., & Abelson, R. P. (1977). Scripts, plans, goals, and understanding: An inquiry into human knowledge structures. Hillsdale, NJ: Erlbaum.

Schmitt, F. O. (1970). Brain cell membranes and their microenvironment. In F. O. Schmitt, T. Melnechuk, G. C. Quarton, & G. Adelman (Eds.), Neurosciences research symposium summaries (Vol 4). MA: The M.I.T. Press.

Schmitt, F. O. (1978). Introduction. In G. M. Edelman & V. B. Mountcastle (Eds.), The mindful brain. Cambridge, MA: The MIT Press.

Selverston, A. I. (1980). Are central pattern generators understandable? The Behavioral and Brain Sciences, 3, 535-571.

Shanklin, N. K. L. (1981). Relating reading and writing: Developing a transactional theory of the writing process. Monographs in language and reading studies (3, US ISSN 0193-4740). Bloomington: Indiana University, School of Education.

Sherrington, C. (1947). The integrative action of the nervous system. New Haven: Yale University Press.

Smith, D. A., & Graesser, A. C. (1981). Memory for actions in scripted activities as a function of typicality, retention interval, and retrieval task. Memory and Cognition, 9, 550-559.

Sperry, R. W. (1943). Visuomotor coordination in the newt (triturus viridescens) after regeneration of the optic nerve. Journal of Comparative Neurology, 79, 33-55.

Sperry, R. W. (1952). Neurology and the mind-brain problem. American Scientist, 40, 291-312.

Sperry, R. W. (1966). Selective communication in nerve nets: Impulse specificity vs. connection specificity. In F. O. Schmitt & T. Melnechuk (Eds.), Neurosciences research symposium summaries (Vol 1), Cambridge, MA: The MIT Press.

Sperry, R. W. (1969). A modified concept of consciousness. Psychological Review, 76, 532-536.

Sperry, R. W. (1976). Mental phenomena as causal determinants in brain function. In G. G. Globus, G. Maxwell, & I. Savodnik (Eds.), Consciousness and the brain. New York: Plenum Press.

Sperry, R. W. (1977). Forebrain commissurotomy and conscious awareness. Journal of Medical Philosophy, 2, 101-126.

Sperry, R. W. (1978). Mentalist Monism: Consciousness as a causal emergent of brain process. The Behavioral and Brain Sciences, 3, 365-366.

Spiro, R. J. (1977). Remembering information from text: The "state of schema" approach. In R. C. Anderson, R. J. Spiro, & W. E. Montage (Eds.), Schooling and the acquisition of knowledge. Hillsdale, NJ: Erlbaum.

Szentagothai, J. (1978). A false alternative. The Behavioral and Brain Sciences, 3, 367-368.

Thatcher, R. W., & John, E. R. (1977). Foundations of cognitive processes. New York: Hillsdale.

Thorndyke, P. W., & Yekovich, F. R. (1980). A critique of schema-based theories of human story memory. Poetics, 9, 23-49.

Uttal, W. R. (1978). The psychobiology of mind. New York: Wiley.

Wall, P. D. (1966). Functional specificity. In F. O. Schmitt & T. Melnechuk (Eds.), Neurosciences research symposium summaries (Vol 1). Cambridge, MA: The MIT Press.

Weiss, P. (1936). Selectivity controlling the central-peripheral relations in the nervous system. Biological Review, 11, 494-531.

Weiss, P. A. (1966). Specificity in neurosciences. In Neurosciences research symposium summaries (Vol 1). F. O. Schmitt & T. Melnechuk (Eds.), Cambridge, MA: The MIT Press.

Wess, O., & Roder, U. (1977). A holographic model for associative memory chains. Biological Cybernetics, 27, 89-98.

White, B. W., Saunders, F. A., Scadden, L., Bach-Y-Rita, P., & Collins, C. C. (1970). Seeing with the skin. Perception and Psychophysics, 7, 23-27.

Wiersma, C. A., & Ikeda, K. (1964). Interneurons commanding swimmeret movements in the crayfish. Comparative Biochemistry and Physiology, 12, 509-525.

Woll, S. B., & Graesser, A. C. (1982). Memory discrimination for information typical or atypical of person schemata. Social Cognition, 1, 287-310.

Zangwill, O. L. (1972). Remembering revisited. Quarterly Journal of Experimental Psychology, 24, 123-138.

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[1]There is a striking parallel between the approach taken by the Roman physiologist Galen (c.AD 130-201) and current information processing psychology--information processing psychology is based on the same type of industrial plant metaphor that haunted Galenian physiology (see Miller, 1978). Galen was concerned with how inanimate matter, as the input to the body via foodstuff, is transformed to animate matter. Internal organs (e.g., the heart, the liver, the lungs) were considered relevant to the extent that they helped carry out such transformations. In Galen's physiology, as in information processing psychology, "the most notable feature of the system is the emphasis on manufacture and transformation . . . processes which convert . . . substances" (Miller, 1978, p. 187).